Argonne NATIONAL LABORATORY

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U.S. Department of Energy

UChicago ▸ Argonne LLC

Office of Science
U.S. DEPARTMENT OF ENERGY

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# Our Energy Future

"What should be the centerpiece of a policy of American renewal is blindingly obvious: making a quest for energy independence the moon shot of our generation"

-- Thomas L. Friedman, New York Times, Sept. 23, 2005.



***Robert Rosner***

***The University of Chicago &***
***Argonne National Laboratory***



***CMAP Climate Change Summit***
***December 11, 2007***

## *Setting the stage: what I will talk about …*

1. Energy demands, US and world-wide
2. Global climate impacts, scenarios
3. Local impacts
4. What can be done: energy alternatives (e.g., conservation, solar, nuclear, wind, biofuels, …)
5. Why are there so much uncertainty?

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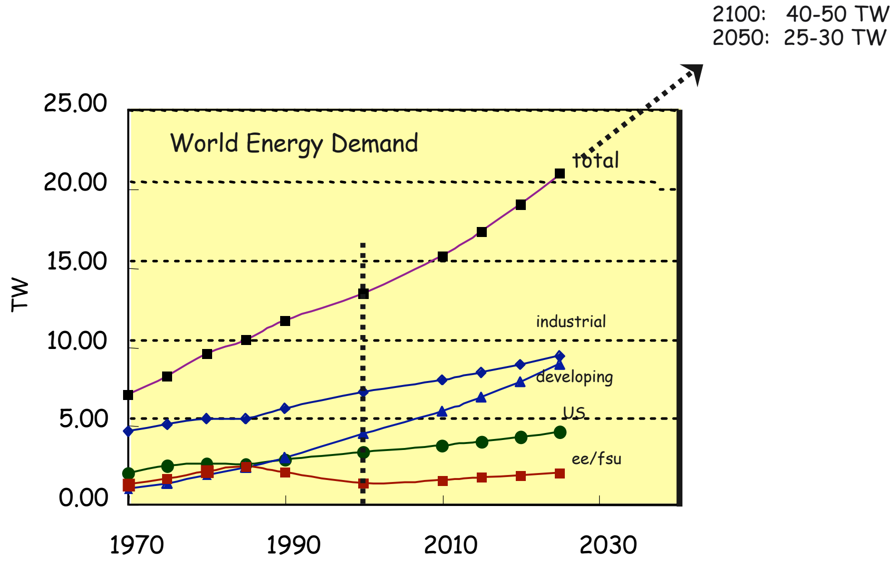
# *The global energy challenge facing us …*

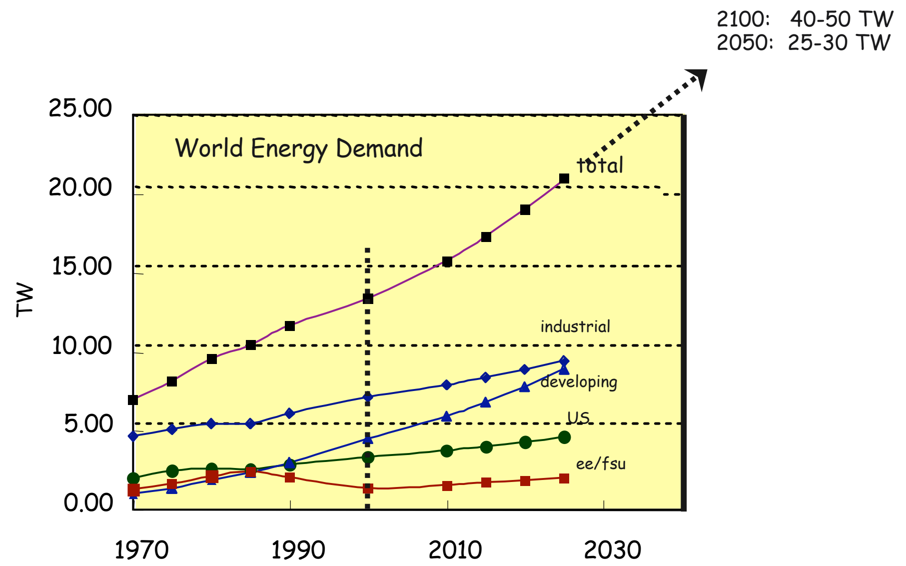



Our starting point is to look at the global picture of global energy consumption.

The key insight is that the vast increase in global energy consumption is not driven by human population increases, but rather by sharply increased expectations of living standards in the developing world …

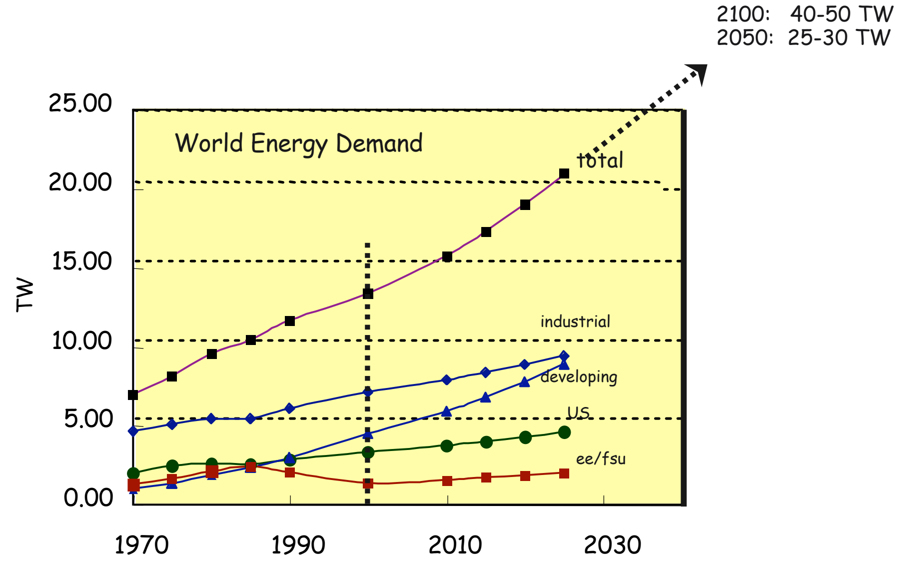
… China, India, Brazil, …

# The challenge - and the energy 'supply' alternatives …




**Conservation** | **Fossil** | **Nuclear** | **Renewable** | **Fusion**

# The challenge - and the energy 'supply' alternatives …



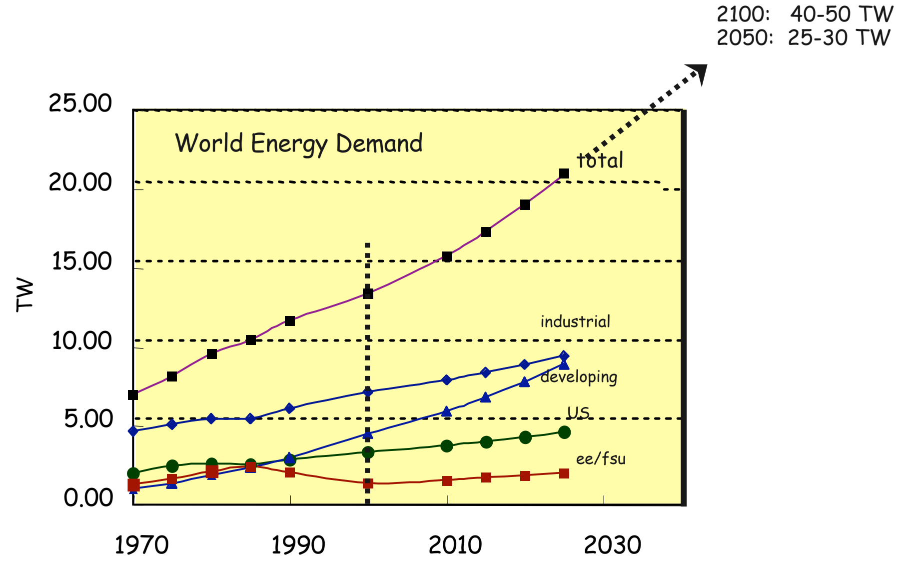

Conservation | Fossil | Nuclear | Renewable | Fusion

**Energy Gap**
~ 14 TW by 2050
~ 33 TW by 2100

10 TW = 10,000 1 GW power plants

1 new power plant/day for 27 years

# The challenge - and the energy 'supply' alternatives …

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Diversity of energy sources required

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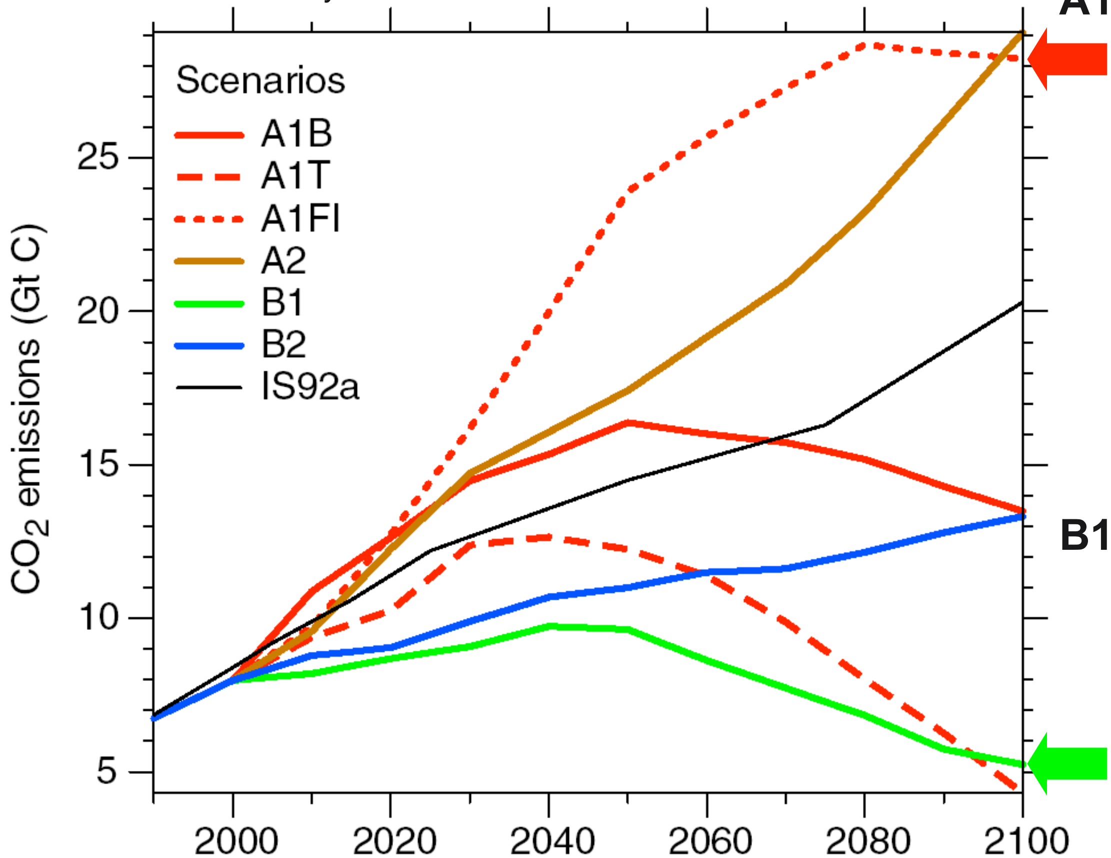
## Scenarios of $CO_2$ emissions from world-wide human activities

In order to understand local consequences of human energy consumption, we need to take the global picture of where global consumption we just discussed, and then understand the resulting global effects on our planet's atmosphere. The local effects will follow from that …

*Thanks to: Katharine Hayhoe and Donald Wuebbles*




**A1FI (higher):** continued dependence on fossil fuels with material-intensive economy

Results:

~970ppm by 2100

~4.5°C mean surface temperature rise

**B1 (lower):** shift to alternative energy sources with service & information-focused economy

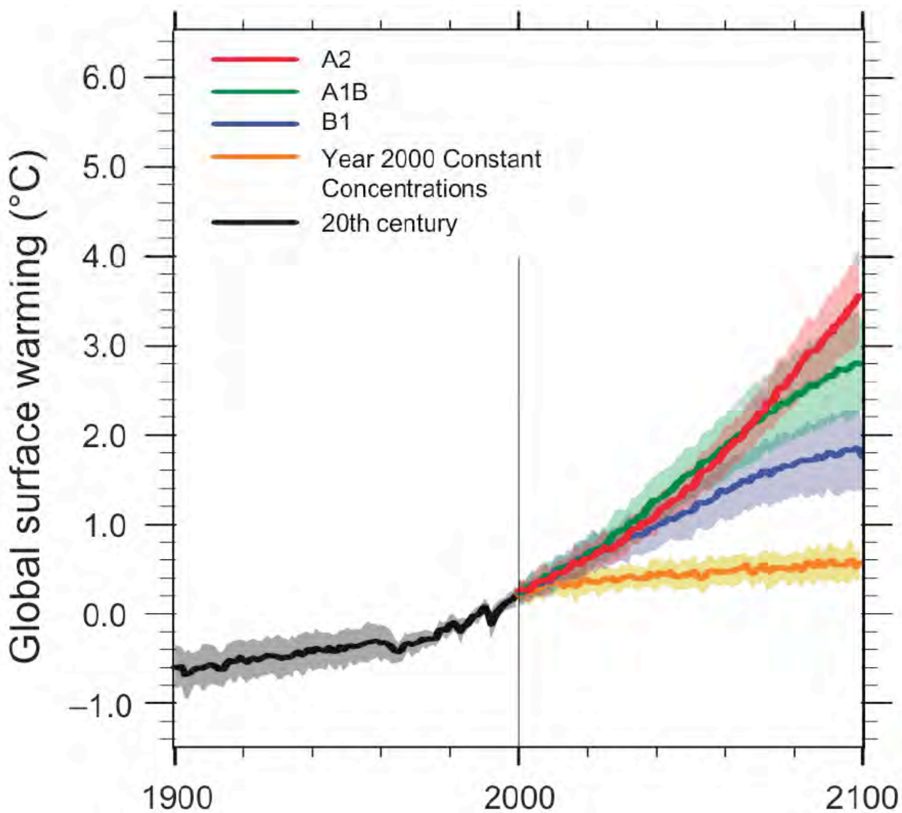
Results:

~550ppm by 2100

~2°C mean surface temperature rise

# *Scenarios of mean temperature increase from world-wide human activities*

A broad range of models based on the previous $CO_2$ loading of our atmosphere are in broad agreement on the consequences for the increase in globally averaged surface temperature …

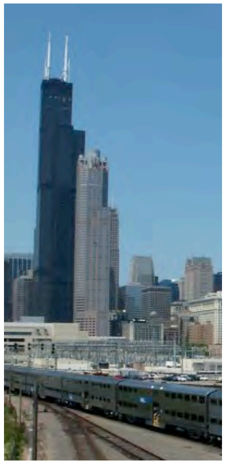



The modeling efforts associated with IPCC 2007 provide a likely range of future globally-averaged surface temperature rise:

**~1.1°C to ~6.4°C**

**(= ~2°F to ~11.5°F)**

## *What I will talk about …*



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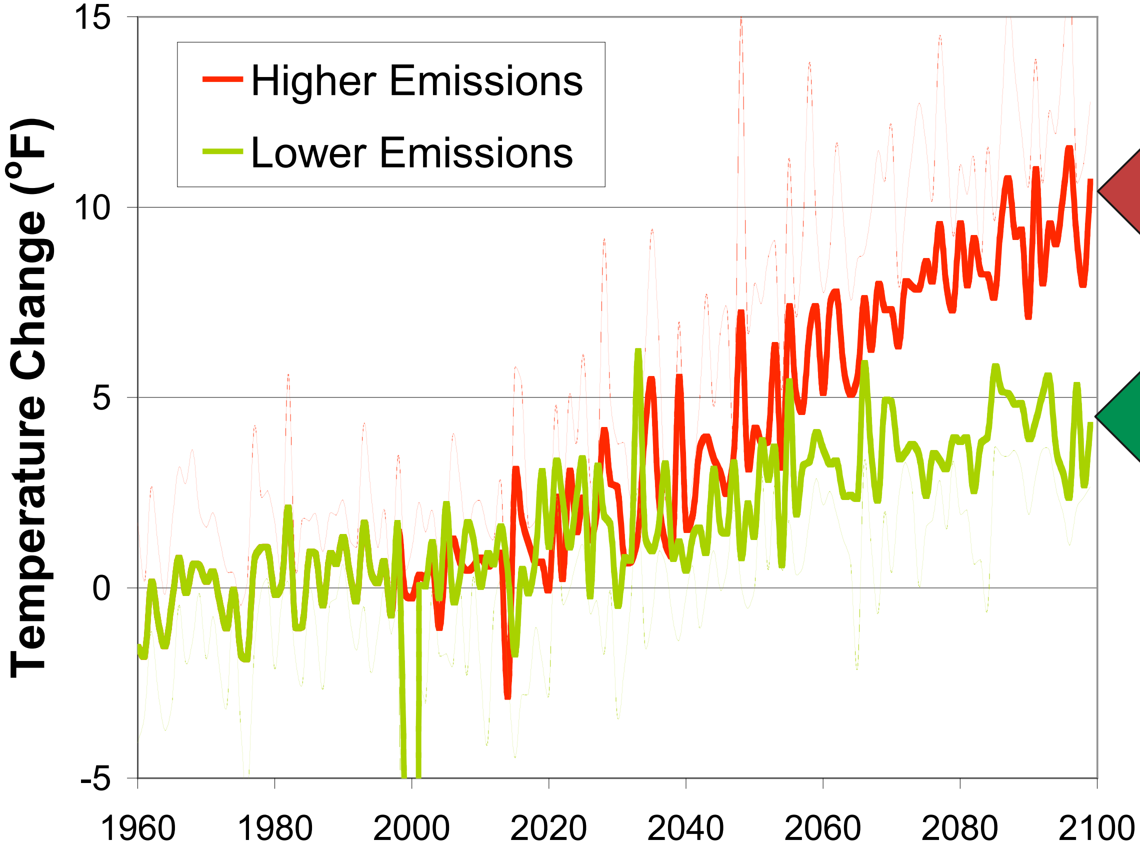
## *The local effects are derived by taking as input the predicted globally averaged conditions …*

- What I will show are some of the results obtained by Katharine Hayhoe and Donald Wuebbles (UIUC) for local effects
- As one goes to more and more detailed (= local) descriptions, significant differences between models do appear
    - *Models differ in how global effects are incorporated in local models*
    - *Models differ in the details of the modeling itself*
- However, model calculations by others do give generally similar results, so that what I will show can be regarded as illustrative of what one does need to think about - and to plan to take into account
- There are many kinds of 'climate metrics' one might use …
    - *Seasonal temperatures*
    - *Extreme temperatures (above or below a certain threshold)*
    - *Degree days*
    - *Precipitation events*
    - *Snow, rain, and heavy precipitation*
    - *…*

# *Example 1: Projections of Chicago's annual average temperature*




The regional models predict:

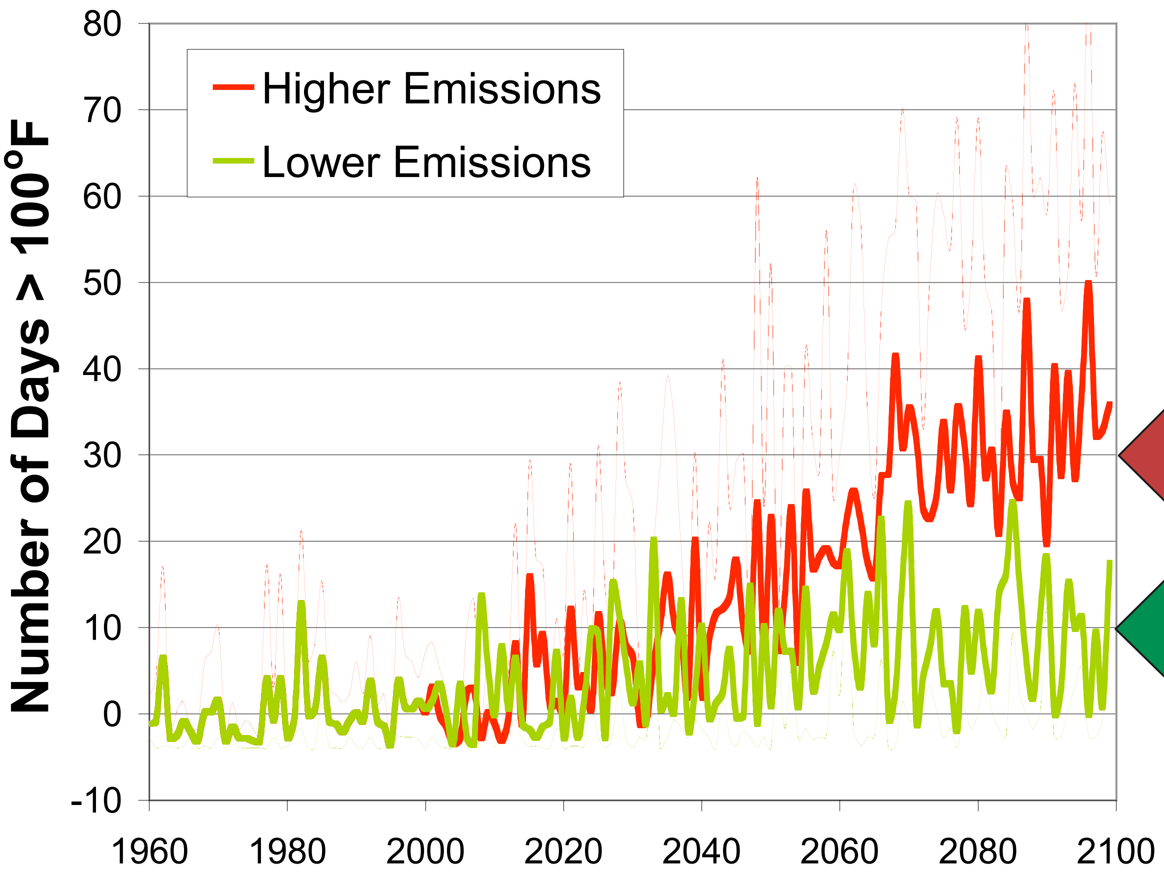
**~5.3-11.2ºF**

**(High emission scenario - 2070-2099)**

**~2.8ºF-5.2ºF**

**(Low emission scenario - 2070-2099)**

## *Example 2: Changes in #s of days with $T_{max}$ > 100ºF*




The regional models predict:

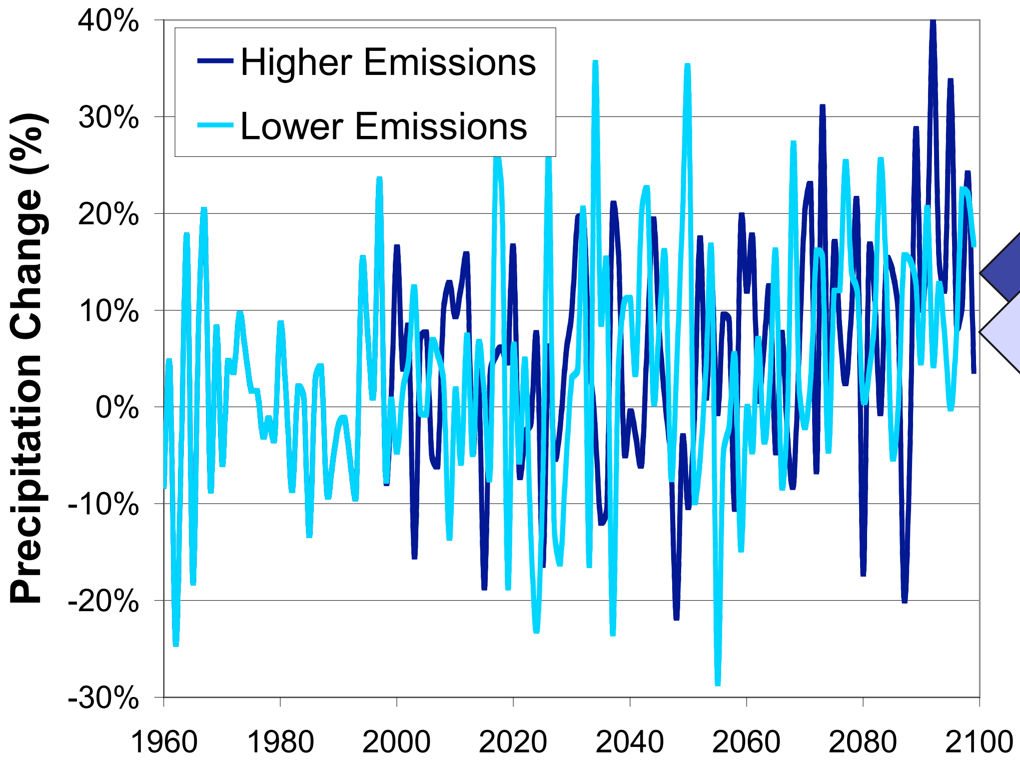
**+ ~30 days**

**(High emission scenario - 2070-2099)**

**+ ~10 days**

**(Low emission scenario - 2070-2099)**

# *Example 3: Change in annual average Chicago precipitation (%)*

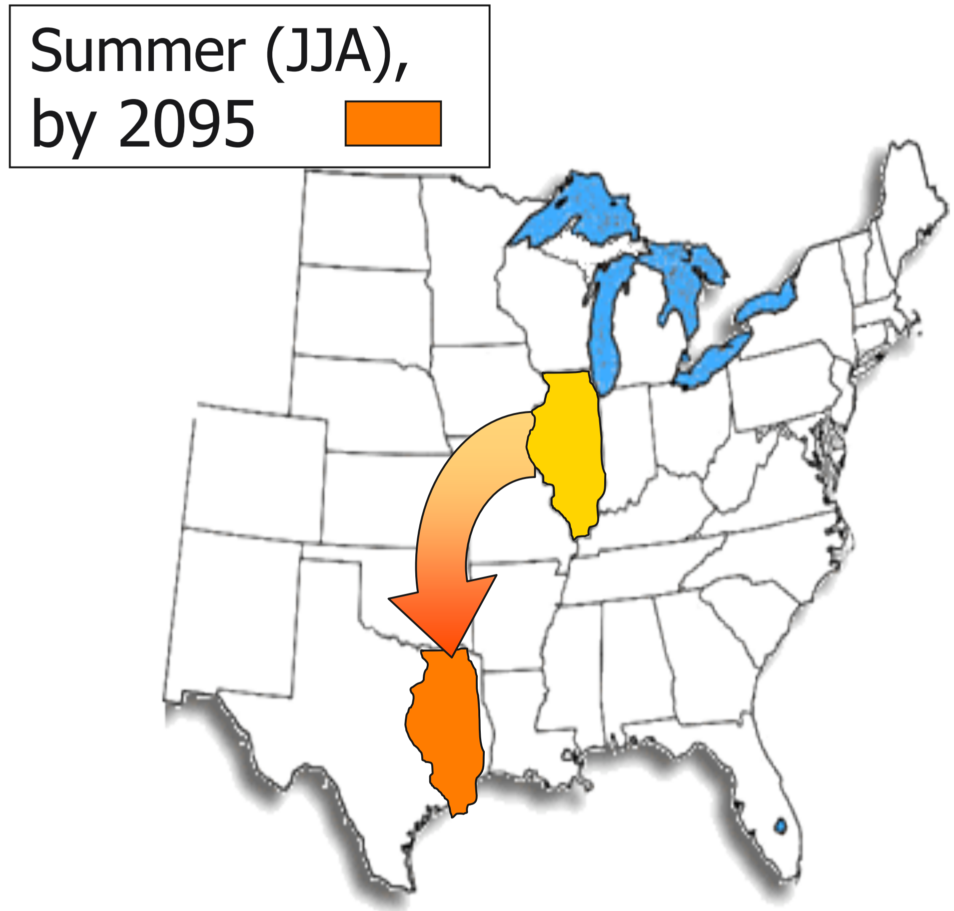



The regional models predict:

**+ 15 %**
**(High emission scenario - 2070-2099)**

**+ 10 %**
**(Low emission scenario - 2070-2099)**

## *Consequence: Illinois' climate will effectively 'migrate' south …*




This picture based on average values of temperature and precipitation - and does not account for variability or special regional aspects.

## *These changes in local climate will have measurable non-climate consequence …*

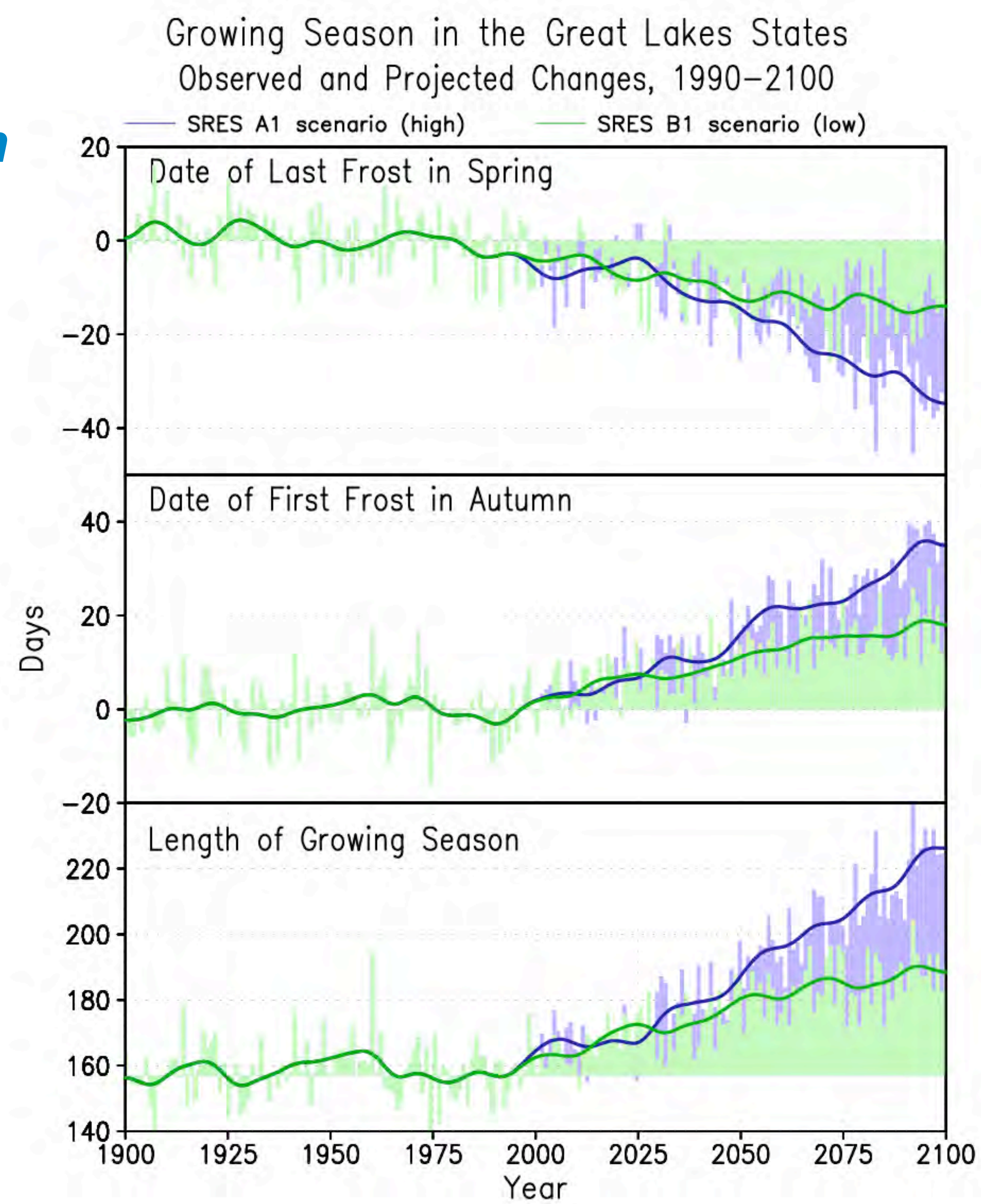
- Agriculture (e.g., growing seasons, harvest periods, pests, …)
- Infrastructure, infrastructure support, viz.,
  - Transportation systems (roads, rail, …)
  - Storm water management
  - Water and air quality
  - …
- Health care system needs
- Parks and lakes: recreation, tourism, …
- Energy use/demands

http://www.usgcrp.gov/usgcrp/nacc/greatlakes.htm

http://www.seagrant.wisc.edu/climatechange/

http://www.ucsusa.org/greatlakes/

## *__For example__: Changes in the length of the growing season in the Great Lakes states …*



## *What I will talk about …*

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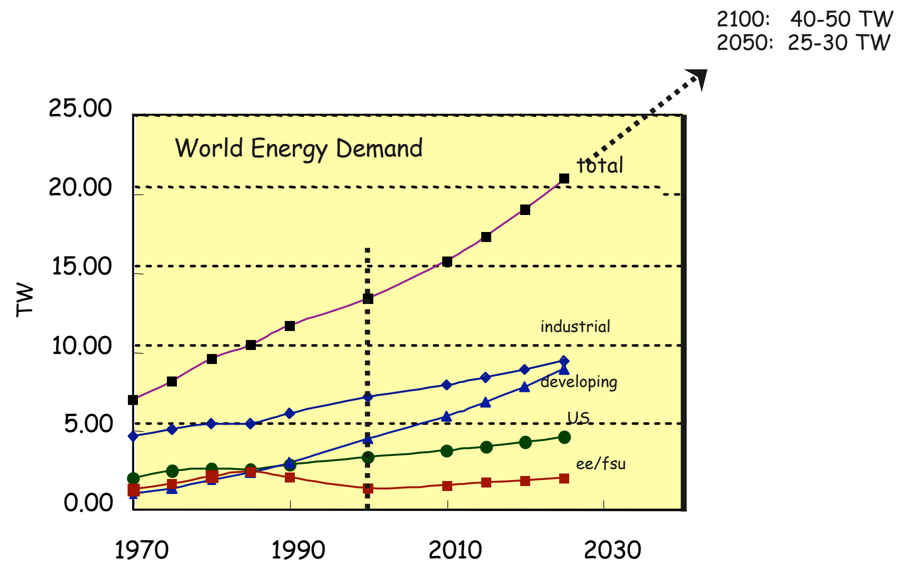
# Recall the energy challenge - and the energy alternatives …




**Energy Gap**
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10 TW = 10,000 1 GW power plants

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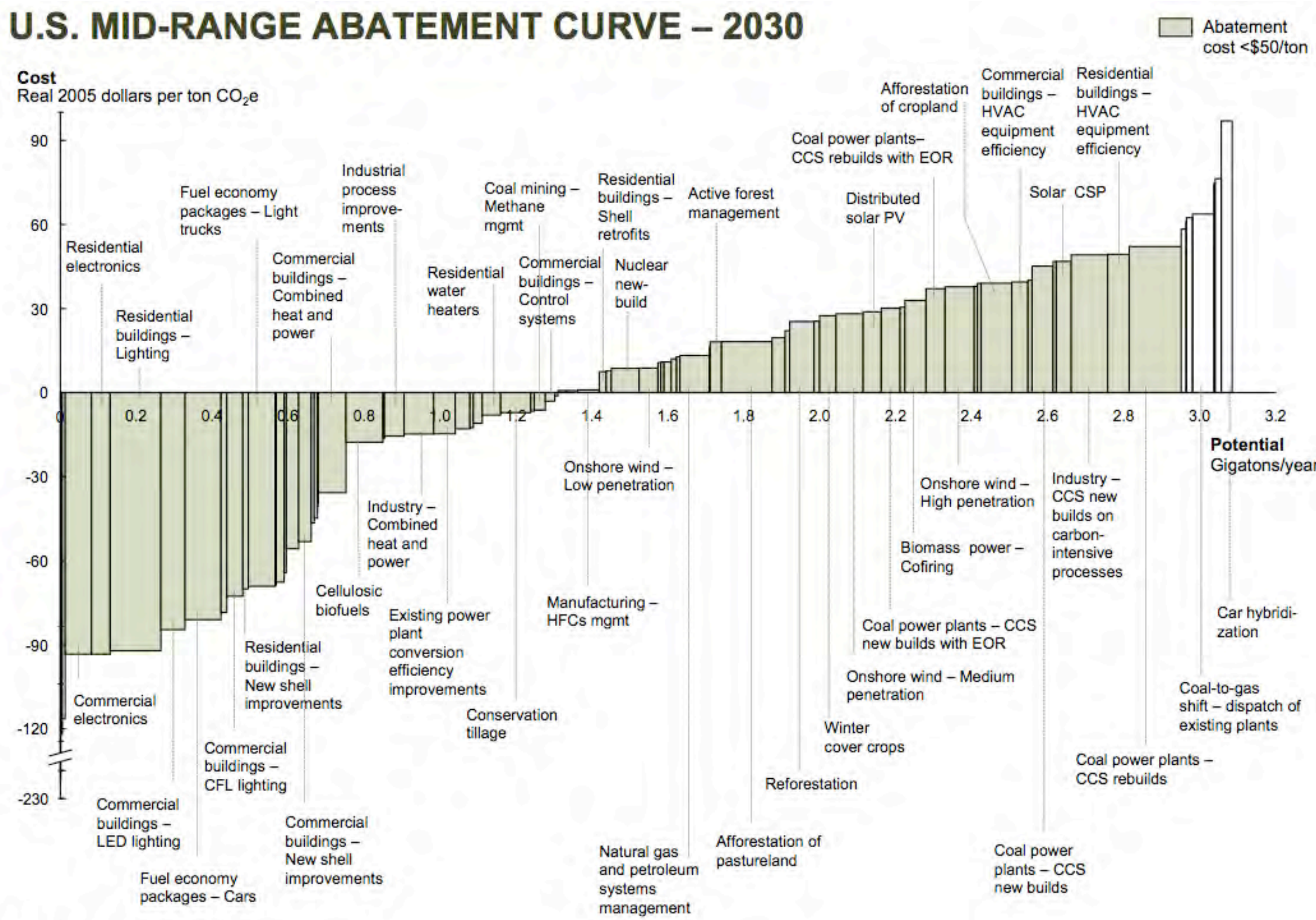
No single solution

Diversity of energy sources required

# … and conservation remains the economic winner by far




Source: McKinsey analysis

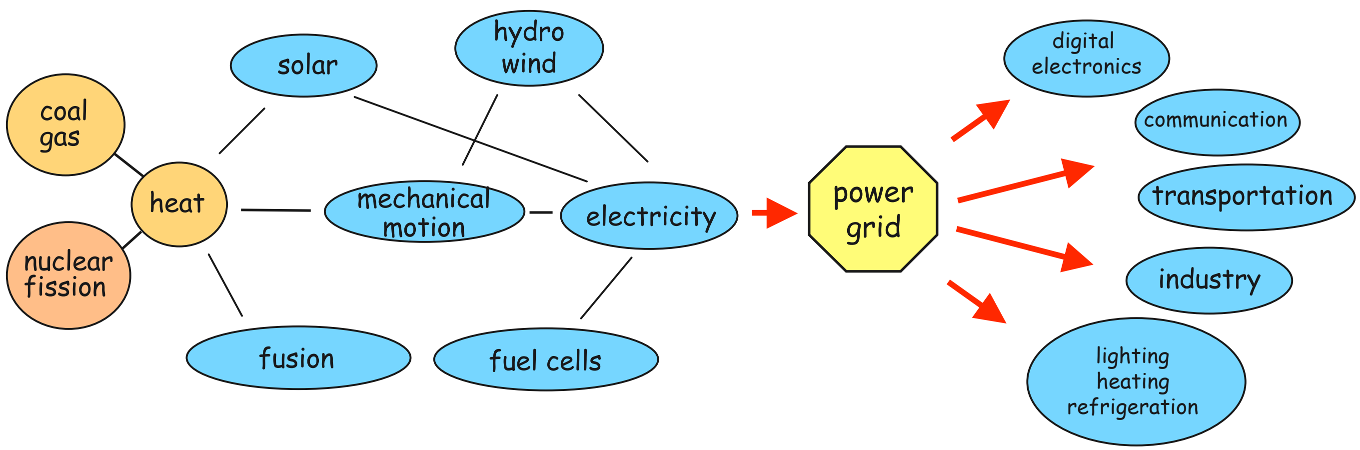
# *Every one of the alternatives faces challenges …*

| Conservation | Fossil | Nuclear | Renewable | Fusion |
|---|---|---|---|---|
| Cannot do it all … | Sequestration? Limited supply? | Economics? Non-proliferation? Spent fuel disposal? | Economics? Fundamental science understanding? | Fundamental science understanding? |

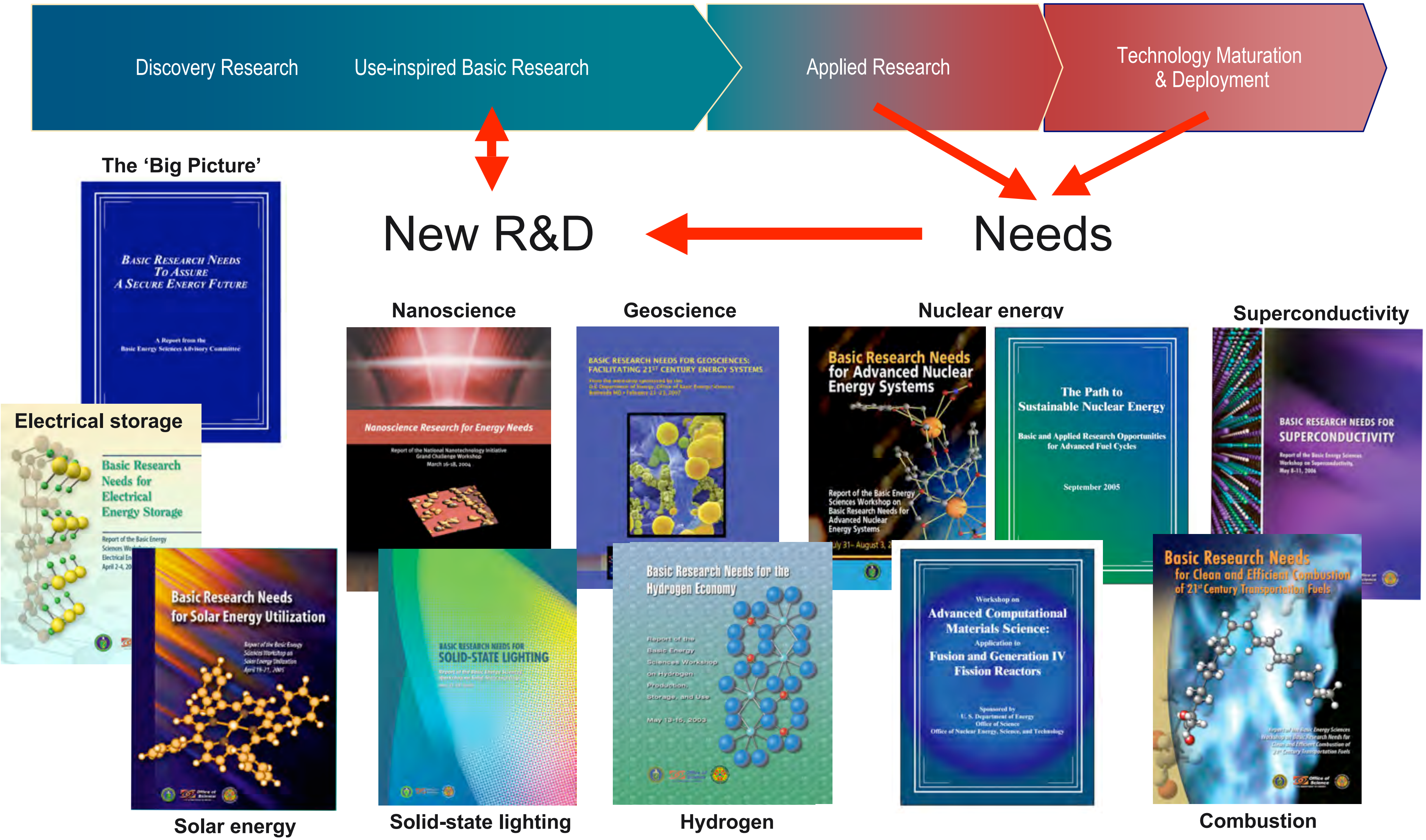
# *Every one of the alternatives faces challenges …*

- **Conservation** → Cannot do it all …
- **Fossil** → Sequestration? Limited supply?
- **Nuclear** → Economics? Non-proliferation? Spent fuel disposal?
- **Renewable** → Economics? Fundamental science understanding?
- **Fusion** → Fundamental science understanding?

## … but there may be a unifying vision:



# *The Department of Energy Laboratory complex is responding to the challenges …*



## *Every one of the alternatives faces challenges … so let’s take one specific example!*

- **Conservation** → Cannot do it all …
- **Fossil** → Sequestration? Limited supply?
- **Nuclear** → Economics? Non-proliferation? Spent fuel disposal?
- **Renewable** → Economics? Fundamental science understanding?
- **Fusion** → Fundamental science understanding?

# 'Renewable Energy' has many facets …

**Energy Gap**
~ 14 TW by 2050
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**Solar**
$1.2 \times 10^5$ TW on Earth's surface
36,000 TW on land (world)
2,200 TW on land (US)

**Wind**
2-4 TW extractable

**Biomass**
5-7 TW gross (world)
0.29% efficiency for
all cultivatable land
not used for food

**Tide/Ocean Currents**
2 TW gross

**Hydroelectric**
4.6 TW gross (world)
1.6 TW technically feasible
0.6 TW installed capacity
0.33 gross (US)

**Geothermal**
9.7 TW gross (world)
0.6 TW gross (US)
(small fraction technically feasible)

# … we'll focus on the potentially most potent renewable energy source

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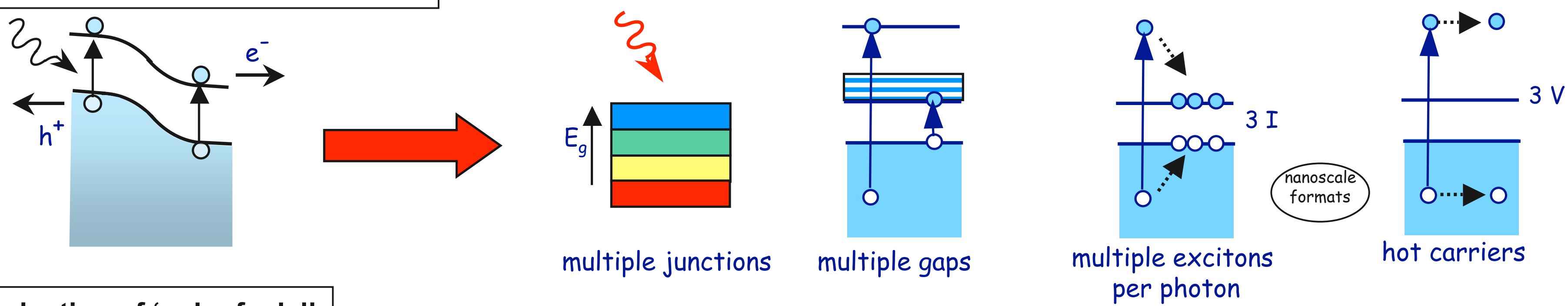
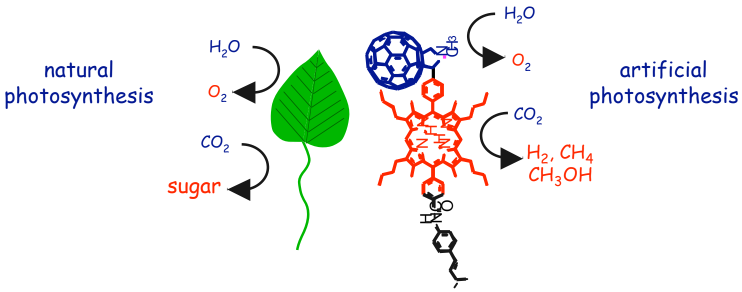
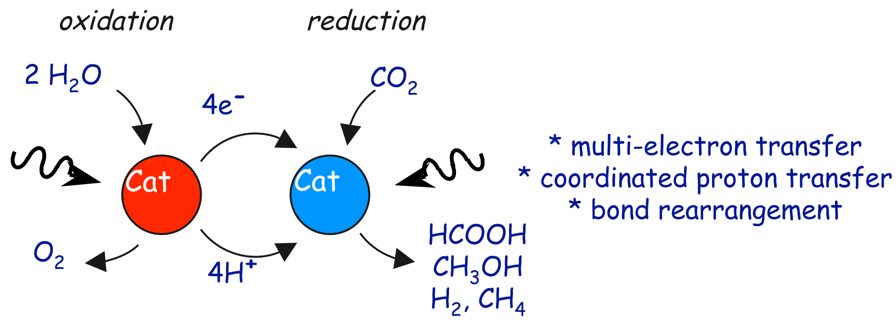
# Solar energy R&D …

## Direct generation of electric power

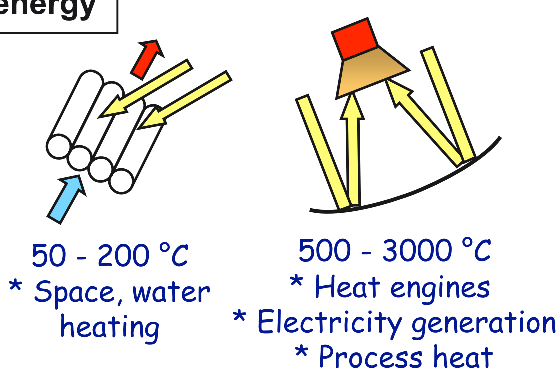


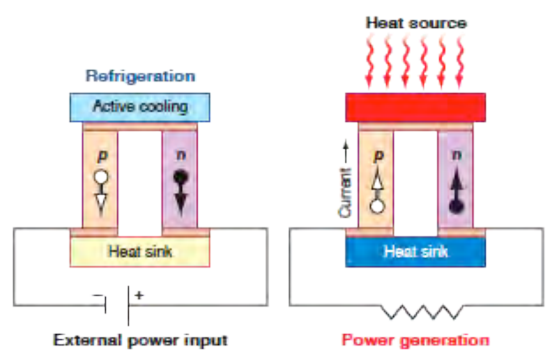

## Production of 'solar fuels''




## Solar thermal energy



## *… in all of these cases, there are unifying and underlying areas of basic research that will enable these new technologies*

- **Example: Replacing expensive raw materials with much cheap raw materials**
  - Can we replace inorganic semiconductors with organic semiconductors?
- **Example: Co-opting biological processes to produce desired materials**
  - Can we produce high-value liquid fuels (e.g., diesels) by biological processes from agricultural waste?
- **Example: Molecular self-assembly & repair at all length scales …**
  - Can we produce materials capable of self-asssembly, autonomous defect detection, and autonomous repair?
    - *The major cost of solar energy conversion is material fabrication …*
    - *Autonomous defect detection and self-assembly provide a route to cheap, efficient, functional production …*

The time span typically separating the basic research leading to these kinds of breakthroughs typically to practical applications is of order 1-2 decades … thus, if we don't invest now in basic research, our future will be inevitably unpleasant …

## *What I will finally talk about …*

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# *What do we want to have, and do, right now?*

- Consider a portfolio of competing energy technologies for supplying (for example) base power: coal, oil, natural gas, nuclear, solar, wind, biofuels/renewables, …
- For each technology, we would like

  **1. Reliable (= verified & validated) predictions of performance/capabilities and costs**

    - *Full accounting of life cycle costs, avoided costs, …*
    - *Projections based on science-based engineering (e.g., must allow analyses to go outside the narrow performance envelope for validated point designs typically defined by today's state of the art engineering)*
      - Sizing up the potential impacts of transformational technologies
    - *Static and dynamic analysis capability*

- Across all technologies, we would like to be able to

  **2. Compute the competitive trade-offs and develop full portfolio analyses (viz., determine an optimal mix of technologies for given constraints)**

- For all technologies, we would like to be able to carry out

  **3. Detailed sensitivity analyses**

    - *Investment decisions (R&D, technology readiness, …)*
    - *Critical path analyses*
    - *Safety …*

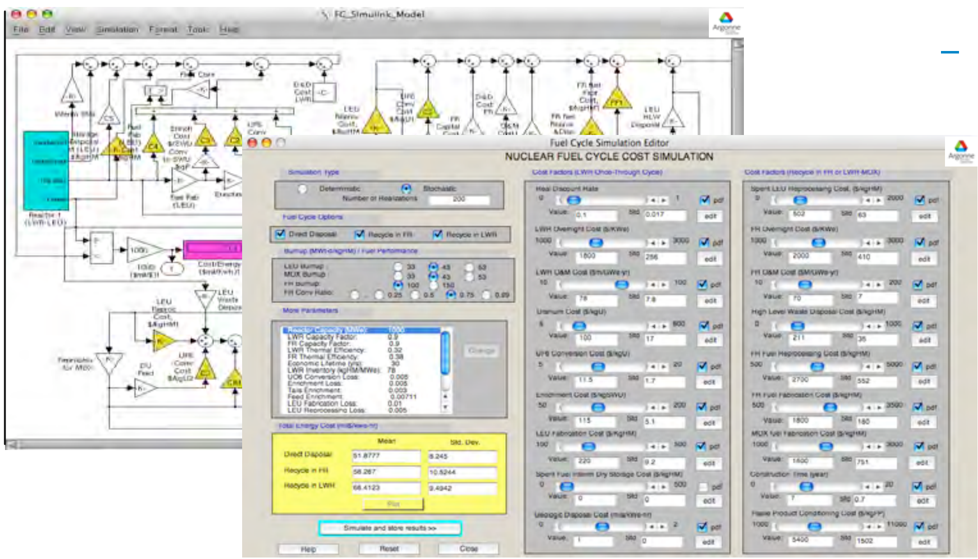
- … and the ultimate dream: to couple these analyses capabilities to climate, social, economic, … , factors

## *What do we have today?*

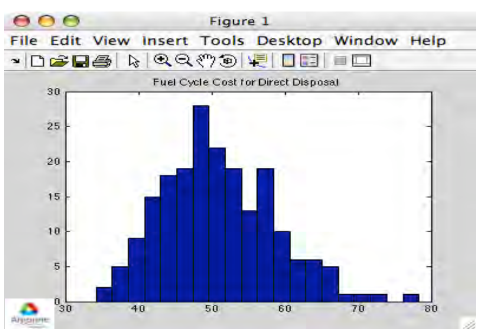
- #1 [=Reliable (= verified and validated) predictions of performance/capabilities and costs], for **some** technologies (e.g., Argonne's GREET & PSAT models)
  - Typically static; a select few are dynamic
  - Typically limited by existing designs (which were used to do V&V), with weak if any reach-back to science-based simulation capabilities
  - Weak (if not totally absent) standards for modeling methodologies, data interchange, module interchange (viz., module interfaces), …
- Thus, we cannot (for example)
  - Credibly compare all existing energy technologies at a systems level (#2)
  - Credibly carry out sensitivity analyses, … (#3)
  - Easily compare the results of different modeling efforts
  - Credibly evaluate transformational technology impacts
- This means, among other things, that
  - Our investment decisions do not have the rigor one might expect …
  - We cannot demonstrate that we know how to optimize our energy portfolio

# *As an exercise, I wanted to compare the CoE for three nuclear fuel cycle options …*

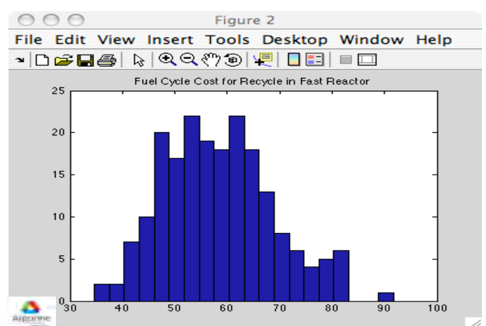
- Thermal LWR, 'once through'
- Closed fuel cycle (using fast spectrum reactor)
- Thermal LWR, recycle/MOX



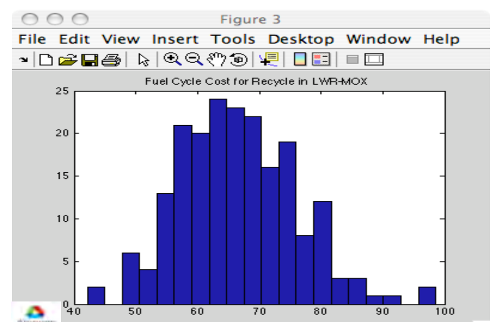

- Note that
  - We can do backwards/sensitivity analyses
  - Competing nuclear technologies can be compared on a 'level playing field'
  - We can ask (and answer) questions about the possible impact of breakthrough technologies
    - *There are direct connections between the science-based reactor, … , modeling codes and the components of this systems-level model*
    - *But we cannot yet*
      - Couple back to simulations of reactors, …
      - Examine dynamical 'reactor fleet' models
      - Fairly compare to non-nuclear technologies
      - …




LWR/Once-Through




Closed Fuel Cycle/Fast Reactor




LWR/MOX Recycle

## *Will existing models improve? Can we be more certain?*

- The modeling schemes are well-validated on existing systems, and therefore - like all engineering models - are not well-suited for analyzing performance/cost/… far from the point design of the validating suite.
- Consistent hierarchical approach to modeling is missing
  - There is no generally accepted methodology for building hierarchical science-based models, e.g., each model is idiosyncratic …
  - This issue is closely related to the problem of building multi-scale models in material science and fluid dynamics
- There is no natural means by which new scientific understanding can be inserted into the existing modeling - insertion is ‘by hand’
  - The existing assessment tools are not well-suited for driving investment decisions for transformational (as opposed to incremental) R&D
- **However**: **the remarkably increasing power of modern massively-parallel computers are dramatically changing what can be done, and will be done, over the next decade - the era of simulation-based rapid prototyping and idea exploration is now upon us …**

## *And that brings us to …*

# Questions and Discussion